Status of the PHOENIX ECR charge breeder at ISOLDE, CERN

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Abstract

We report here on the last progresses made with the PHOENIX ECR charge breeder test bench at ISOLDE. Recently, an experiment was performed to test the trapping of ^{61}Fe daughter nuclides from the decay of ^{61}Mn nuclides. Preliminary results are given.

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I. INTRODUCTION

In the perspective of future applications of charge bred beams to nuclear physics or solid states physics experiments, a PHOENIX ECR Booster is undergoing performance tests at ISOLDE. A first part of the investigation of the on-line performances of the ECR charge breeder was presented at ICIS05 [1], showing preliminary results of the afterglow method with stable beam. As a second step, beam times planned for this year concentrate on three topics: the study of the dependence of the charge breeding process on the chemical properties of the injected ion beam, the possibility of trapping and charge breeding daughter nuclides in the plasma, and the tests of the afterglow method with radioactive ion beams.

A. Status of the PHOENIX ECR Booster test bench

The PHOENIX ECR Booster is installed as a test bench on the Heavy Masses beamline after the General Purpose Separator (GHM) at ISOLDE [2], as shown on Fig. 1. Singly charged ions produced by ISOLDE are injected into the charge breeder where they are stepwise ionized by collisions with energetic electrons of the ECR plasma [3]. After extraction, the charge states are separated by a 102° magnetic dipole and directed towards either a faraday cup, or a tape station set up after the faraday cup at the end of the beamline. Various technical developments have been undertaken, which were described in previous references [4].

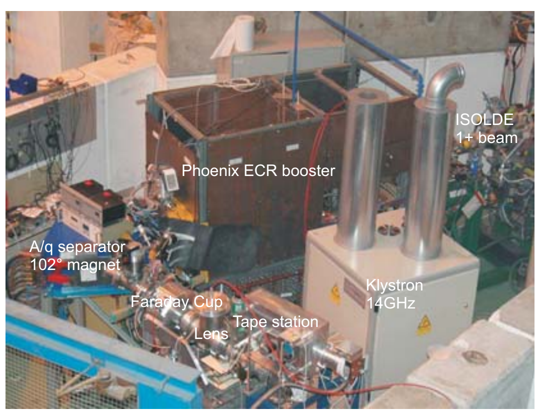

FIG. 1: Layout of the PHOENIX ECR Booster test bench in ISOLDE hall

B. Program of investigation

The current program for tests [5, 6] is mainly dedicated to the study of the performances of the ECR charge breeder in view of its future use at RIB facilities, i.e. as the first part of a postaccelerator, or as a stand-alone device for preparing beam for nuclear physics experiments. Several applications of the latter type have already been imagined, leading to experiments [7], and more recently to the proposal of new experiments [8–10]. In these cases, the ECR charge breeder is used as a purifying device, either by using the charge state distribution for ions of different Z values, or the injection and breaking up of molecular sidebands from the ISOLDE target and ion source. At last, a test of the trapping of the daughter nuclides has been recently performed, which could open possibilities for the production and study of new radioactive ion beams.

II. CHARGE BREEDING OF DAUGHTER NUCLIDES

In some specific cases, beams of isotopes that are not directly accessible with the ISOL production method can be produced from the beta decay of their mother nuclide. One possible method is the trapping of the mother nuclides for several half-lives. Such a technique was used by the ISOLTRAP experiment to measure the mass of neutron-rich iron isotopes [11, 12] that are not directly produced at the ISOLDE facility [13].

In order to estimate the efficiency for trapping and charge breeding a daughter nuclide within the ECR plasma, a similar experiment was performed with the PHOENIX Booster.

A. Experimental setup

^{61}Mn isotopes were produced by the bombardment of an UCx target by pulses of 10^{13} protons delivered from the PS booster at an energy of 1.4 GeV, and ionized by resonant laser ionization. They were injected during a fixed time into the PHOENIX Booster, where the axial magnetic field was configured in trapping mode. The time between the end of the injection and the afterglow pulse, that is refered in the following as trapping time, could be varied from one measurement cycle to another around the half-life of ^{61}Mn, i.e. 670 (40)ms [14]. The measurements were repeated over cycles of 30 min. ^{61}Mn decays to ^{61}Fe which has a half-life of 5.98 (0.06)min [14]. After the trapping time, charge bred ^{61}Mn ions are released, and possibly some charge bred ^{61}Fe ions as well, as an afterglow pulse. After charge state separation, they are implanted on a tape shown on Fig. 2 for beta-gamma coincidence measurement.

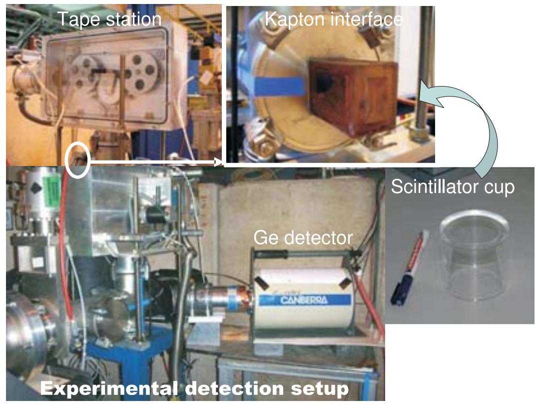

FIG. 2: Detection setup at the end of the PHOENIX Booster beamline. A NE102 scintillator cup surrounds the implantation point for beta counting, and a Germanium detector positioned close to the scintillator provides gamma identification.

As shown in Fig. 3, each measurement starts with one proton pulse and ends with the tape motion for the removal of most of the remaining activity. The analyzing magnet was set to select mass 61 with a 12+ charge state.

B. Preliminary results

The beta-gamma events were recorded using a Time-to-Amplitude-Converter (TAC) showing the time structure of the coincidences. As shown on Fig. 4, the proportion of events recorded as "gamma-gamma coincidences" is quite high as compared to the beta-gamma coincidence events. Such an effect might come from the thickness of the scintillator that provides a double counting of the gammas, as well as from the high X-ray background.

Once gating on the beta-gamma coincidences, the gamma spectrum as given in Fig. 5 allows identification of the ^{61}Mn and ^{61}Fe main lines. By gating on these respective gamma lines, the decay curves of ^{61}Mn and ^{61}Fe were plot, as shown on Fig. 3. At this stage, more analysis is required for suppressing the background coming from deposition of part of the charge bred beam around the tape, and for determining the respective parts of the ^{61}Fe

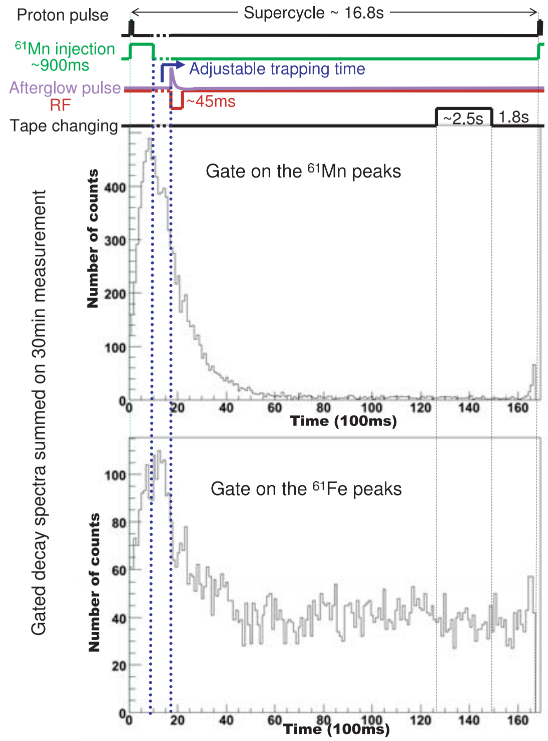

FIG. 3: Decay curves of ^{61}Mn and ^{61}Fe for a measurement cycle of 30min with 800ms trapping. The timing of the measurements is given on the diagram above.

gamma lines coming from the implantation onto the tape of ^{61}Mn^{12+} or ^{61}Fe^{12+}. For similar reasons, the expected increase of the activity after the afterglow pulse is also not visible on these spectra. As it was observed for the charge states of stable ^{16}O, the afterglow pulse sits on the top of a small DC level that was difficult to suppress completely during the time of the experiment. Finally the exponential decay law followed by the two isotopes smears and spreads out the time structure of the pulse.

For background suppression, other types of cycles were realized with the beam gate off (no injection of ^{61}Mn^{+}), and the faraday cup blocking or not the way of the charge bred beam to the tape station. Fig. 6 shows an example of a sequence of cycles for no trapping time. Remarkable enough, the soudain drop of the average activity for the ^{61}Fe beta-gamma coincidences between the last two cycles (beam gate off for both, faraday cup out for the first one and in for the last one) indicates that there was still some ^{61}Fe^{12+} coming from the ECR plasma for long times after the injection of ^{61}Mn was stopped. Obviously a part of the

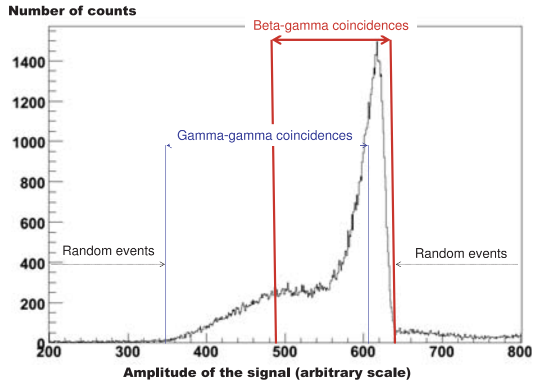

FIG. 4: Zoom on the coincidence events of the Time Amplitude Converter (TAC) spectrum for a measurement with 800ms trapping time.

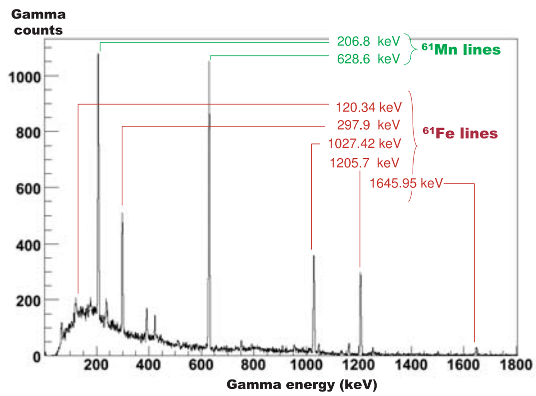

FIG. 5: Gamma spectrum gated on the coincidence events for a 30 min measurement cycle with 800ms trapping.

^{61}Fe isotopes could be kept or recycled in the plasma over times probably larger than 1 min.

III. OUTLOOK

The mechanism of trapping or recycling of ^{61}Fe daughter nuclides from the decay of ^{61}Mn observed in this experiment will be further investigated by a more detailed analysis. A careful suppression or treatment of the background should permit to obtain more information about

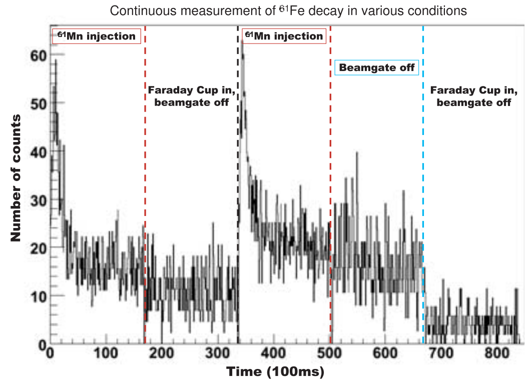

FIG. 6: Decay curve of ^{61}Fe for successive cycles (normalized on 30min each) and no trapping time. The count rate drops significantly in the last section with the insertion of the Faraday Cup: this shows that ^{61}Fe isotopes were still released from the plasma while the beamgate was off in the previous cycle.

its nature and quantitative results concerning its efficiency.

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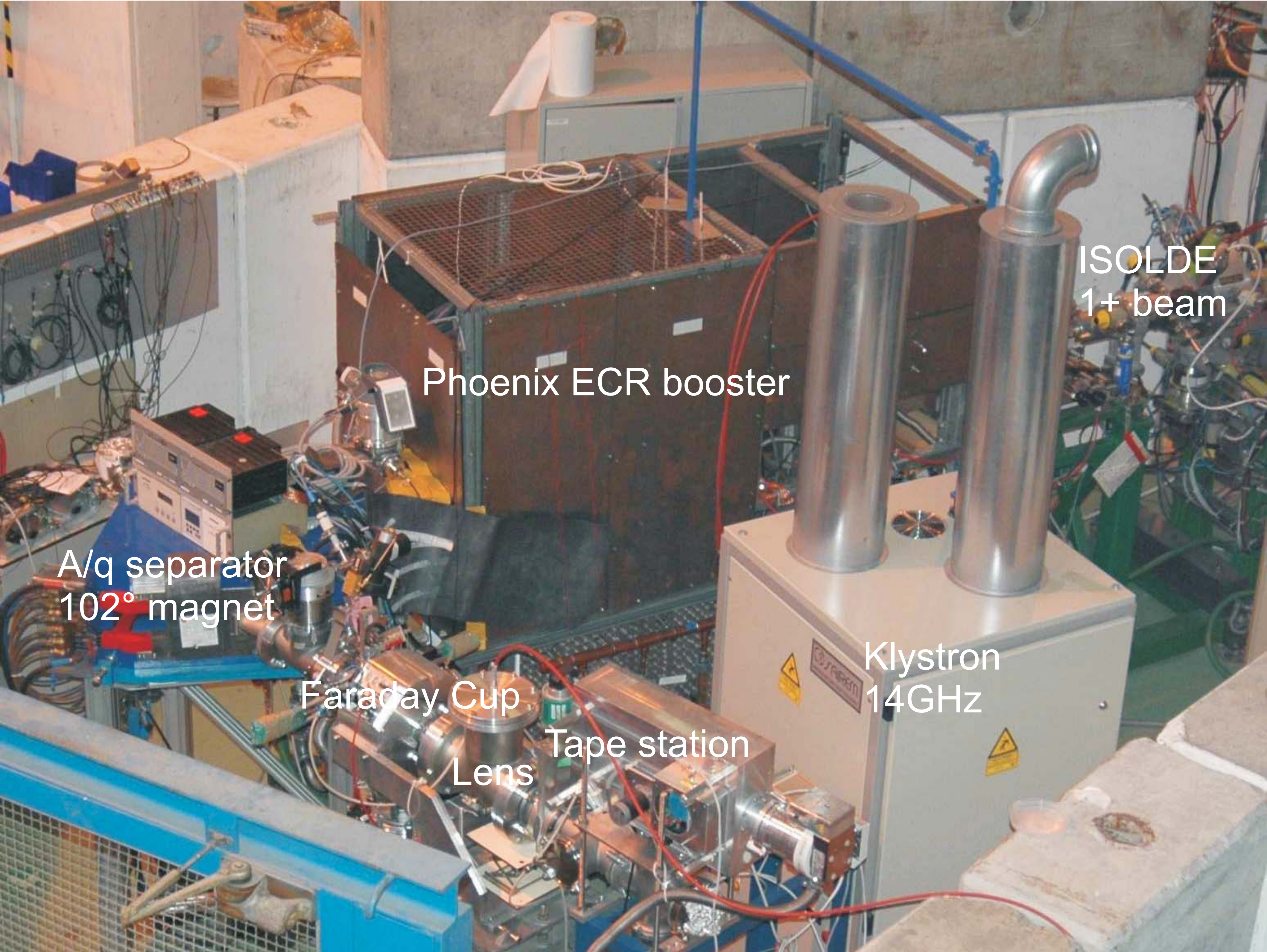
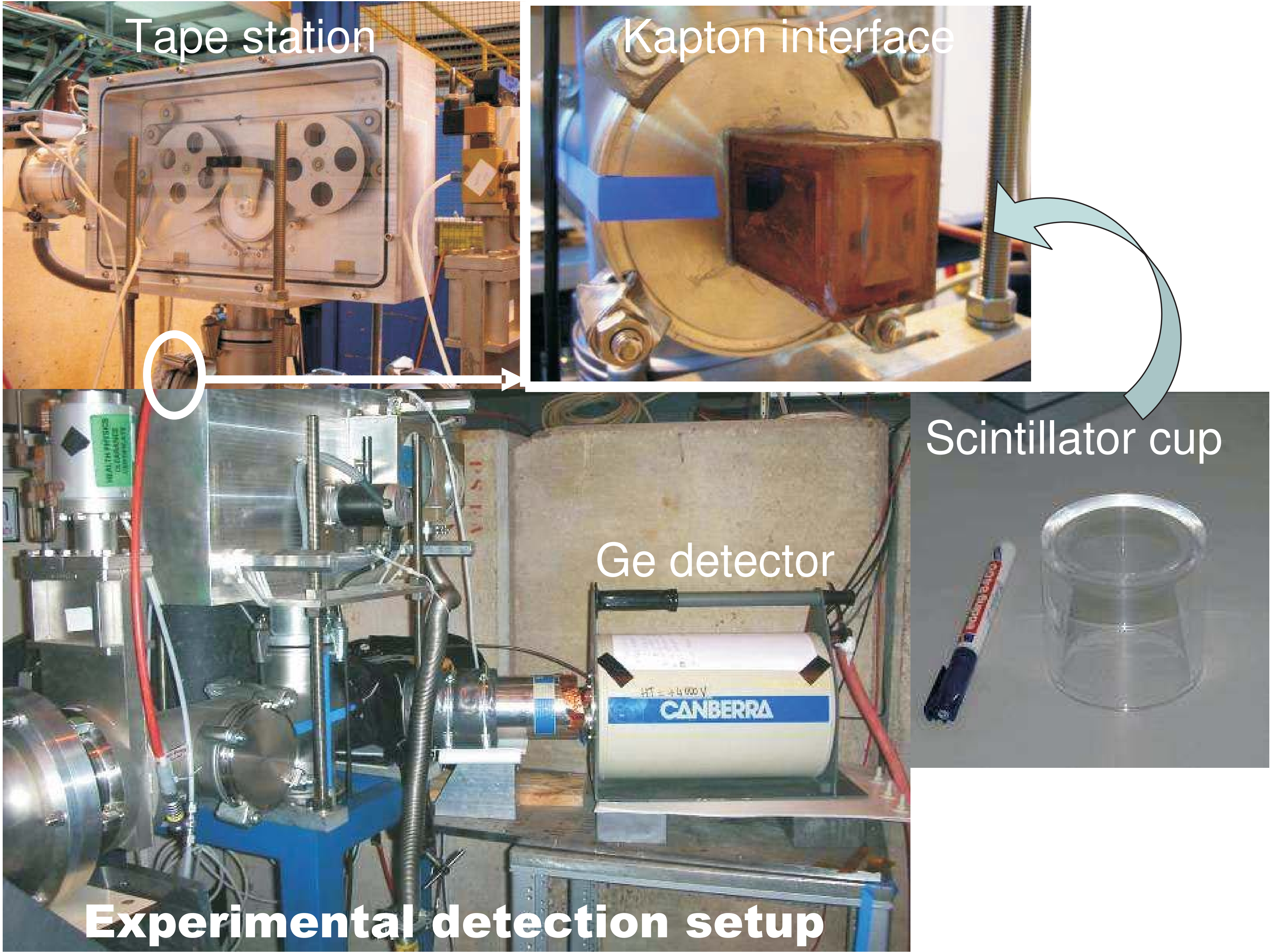
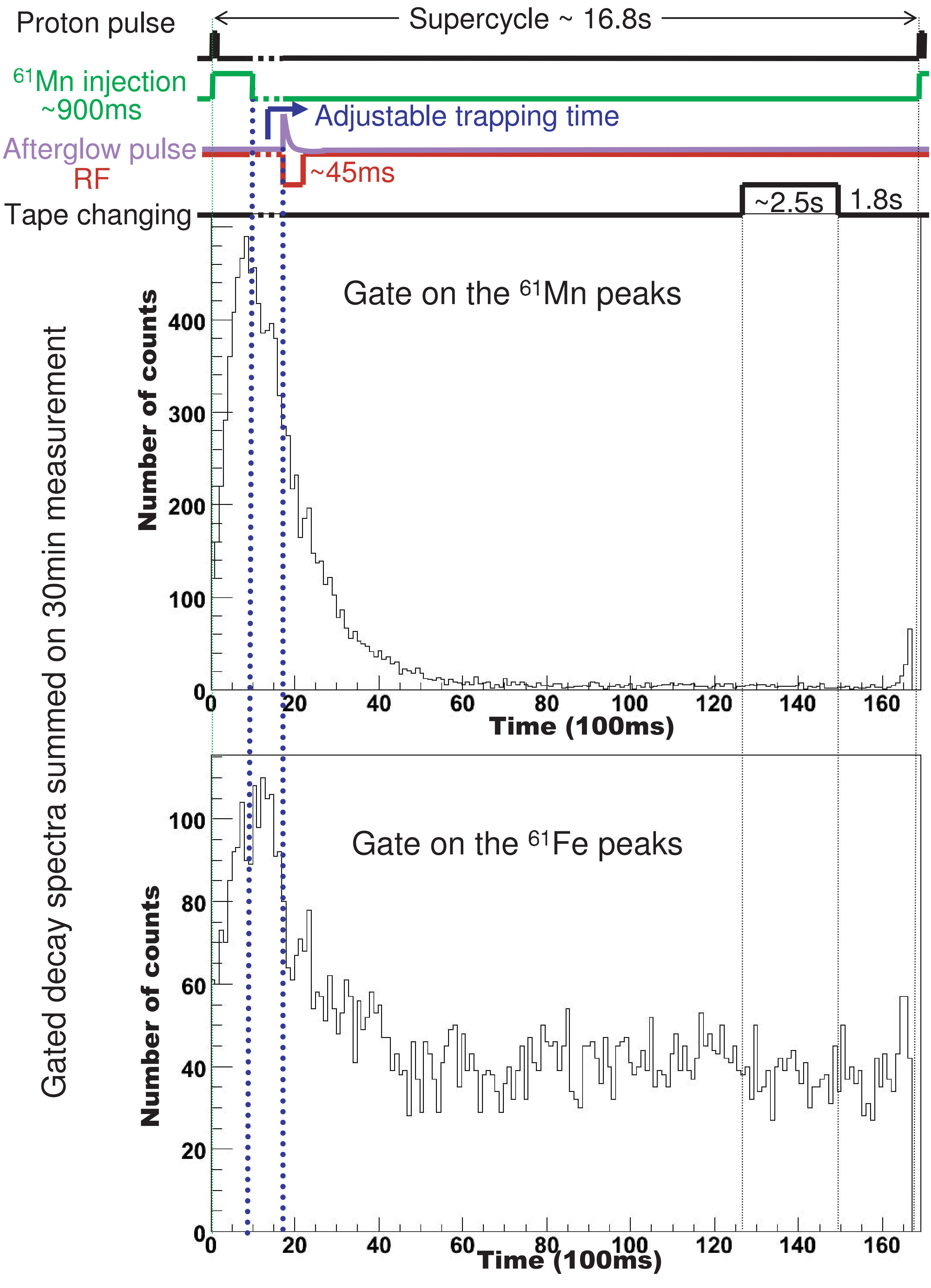
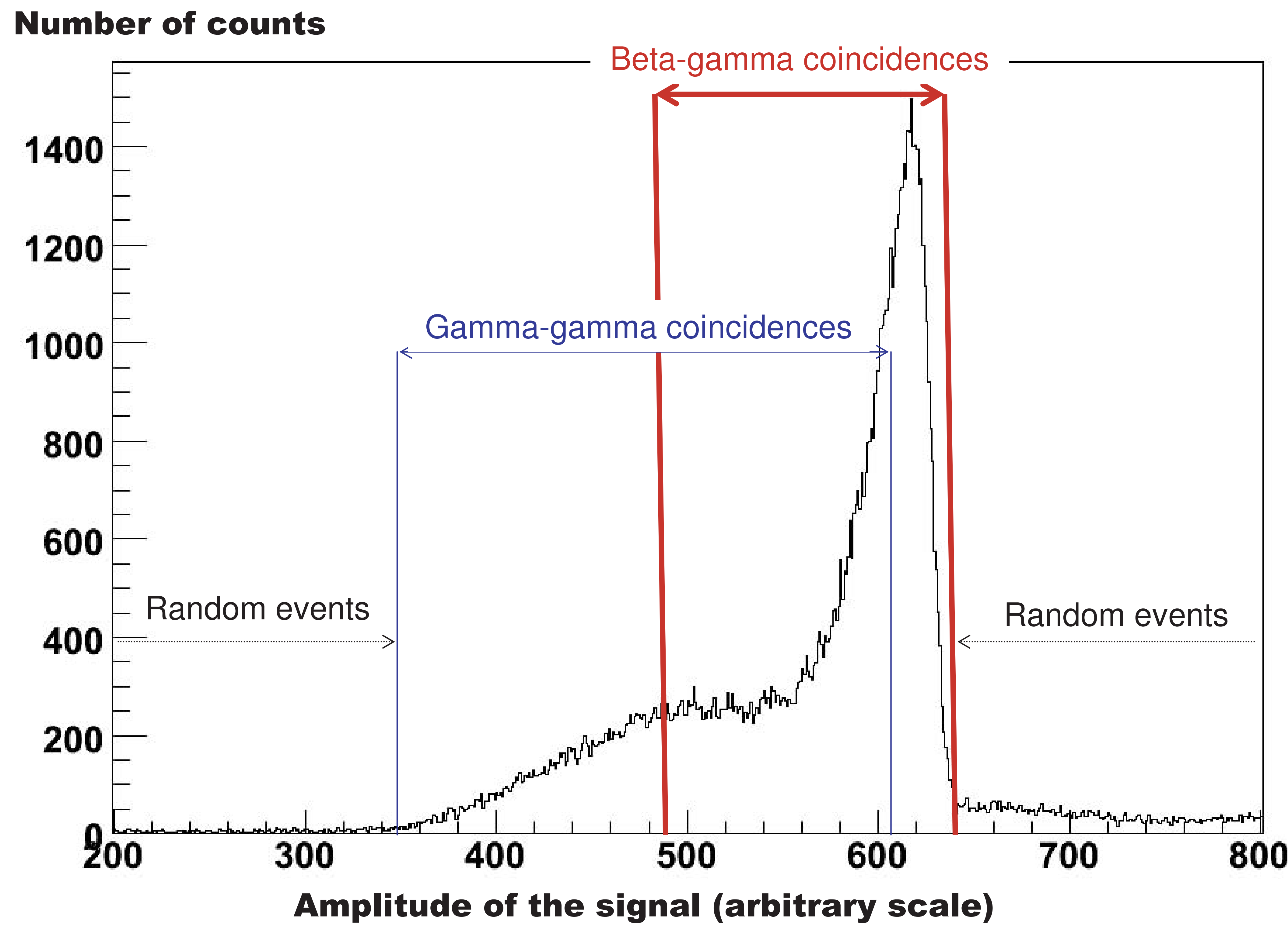
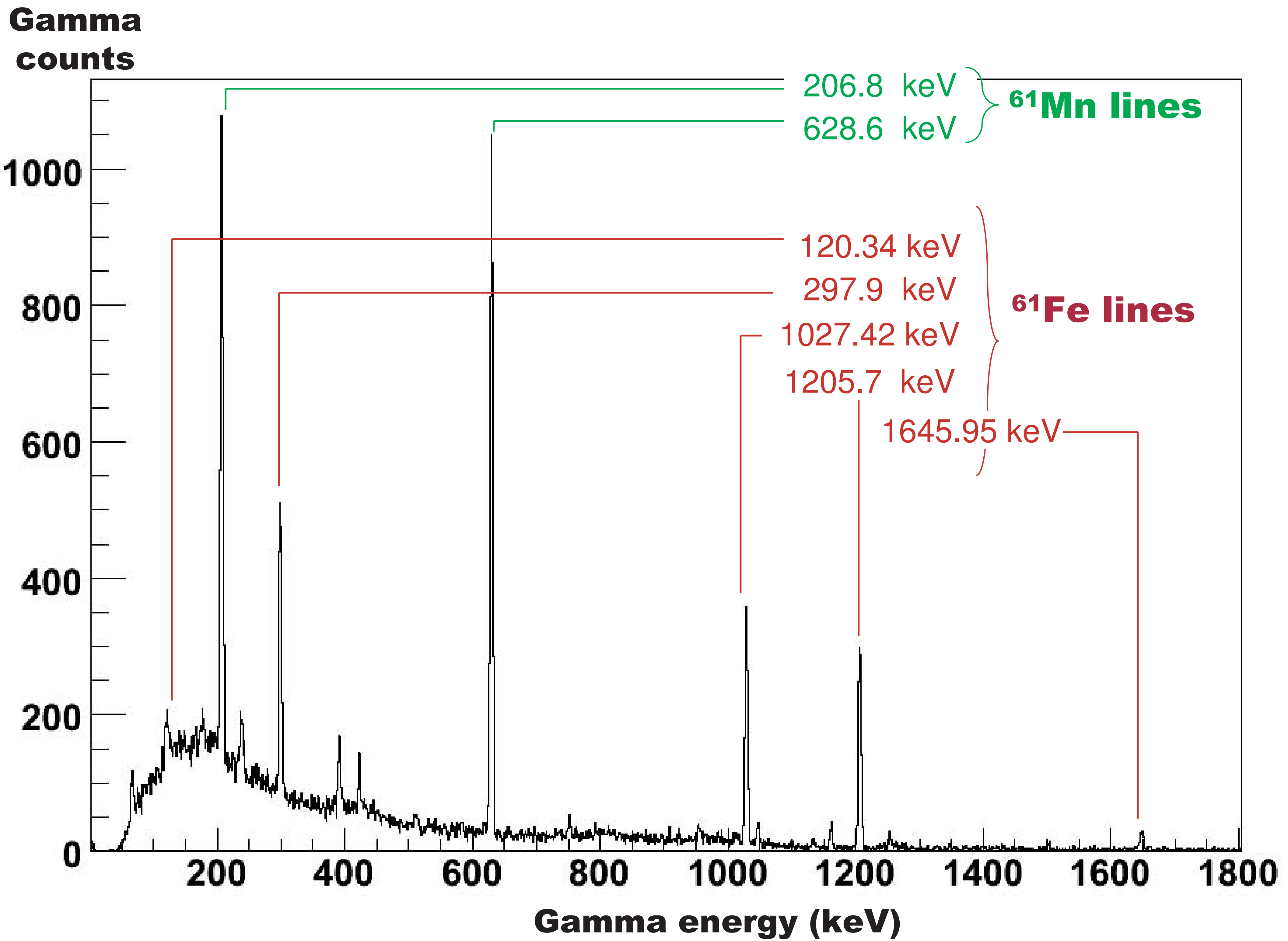

ISOLDE
1+ beam
Phoenix ECR booster
A/q separator
102° magnet
Klystron
14GHz
Faraday Cup
Tape station
Lens


Tape station
Kapton interface
Scintillator cup
Ge detector
CANBERRA
Experimental detection setup

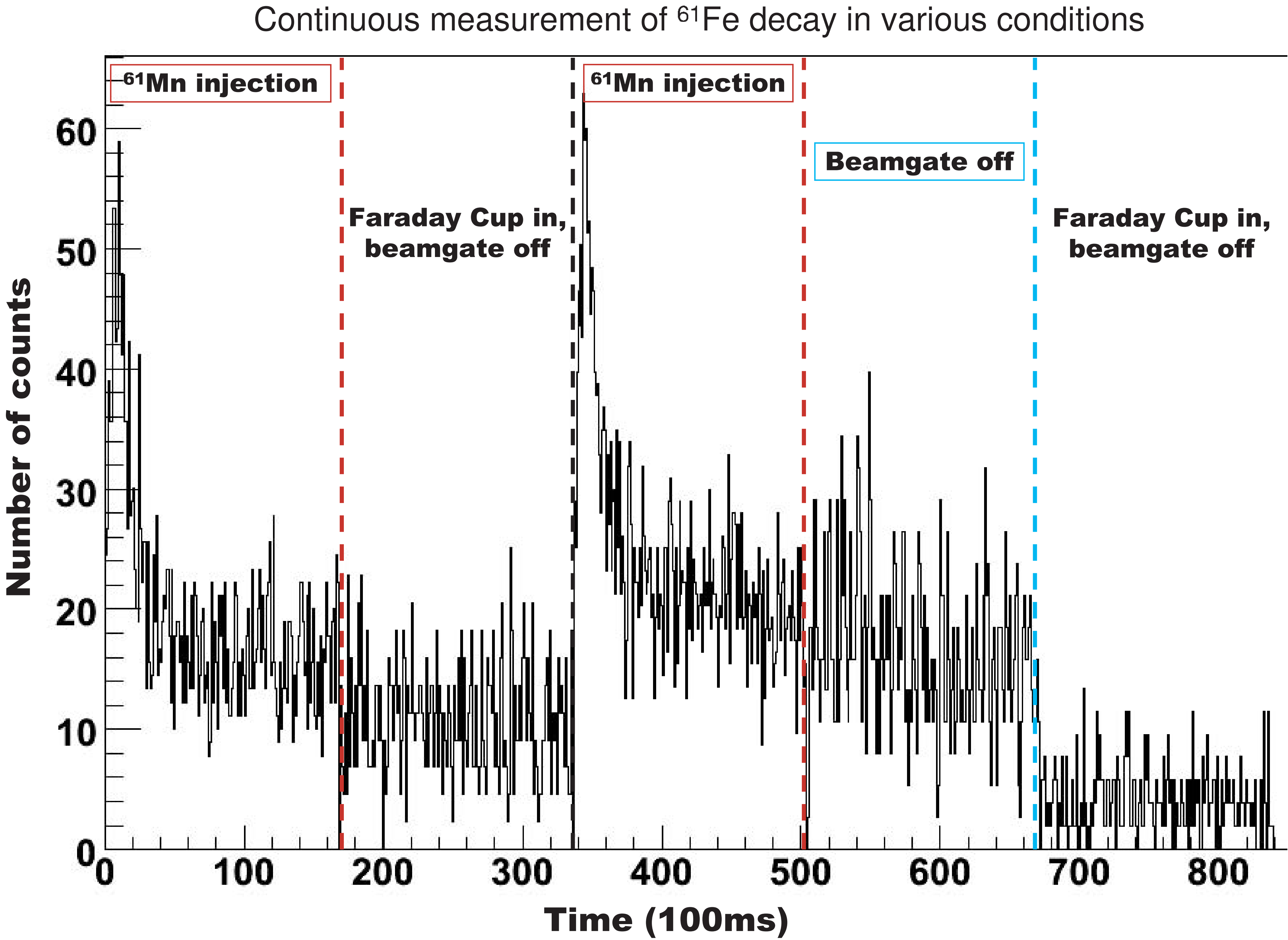


Proton pulse
Supercycle ~ 16.8s
^{61}Mn injection
~900ms
Adjustable trapping time
Afterglow pulse
RF
~45ms
Tape changing
~2.5s
1.8s
Gated decay spectra summed on 30min measurement
Gate on the ^{61}Mn peaks
Number of counts
Time (100ms)
Gate on the ^{61}Fe peaks
Number of counts
Time (100ms)


Number of counts
Beta-gamma coincidences
Gamma-gamma coincidences
Random events
Random events
0
200
400
600
800
1000
1200
1400
200
300
400
500
600
700
800
Amplitude of the signal (arbitrary scale)



Gamma counts
1000
800
600
400
200
0
200
400
600
800
1000
1200
1400
1600
1800
Gamma energy (keV)
206.8 keV
628.6 keV
61Mn lines
120.34 keV
297.9 keV
1027.42 keV
1205.7 keV
1645.95 keV
61Fe lines



Continuous measurement of 61Fe decay in various conditions
61Mn injection
Faraday Cup in, beamgate off
61Mn injection
Beamgate off
Faraday Cup in, beamgate off
Number of counts
Time (100ms)
0
10
20
30
40
50
60
0
100
200
300
400
500
600
700
800